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Comparison between thermospheric neutral density and ionospheric electron density from TIEGCM and empirical models

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1. Introduction

The precise knowledge of the density within the atmospheric layers is important in many applications, e.g. positioning, navigation and satellite orbit determination. In this contribution, the neutral density is considered for analysis of the thermosphere characterization using Thermosphere Ionosphere Electrodynamics General Circulation Model (TIEGCM) software and compared with the neutral densities derived from empirical models such as NRLMSISE, JB2008. Different empirical models use slightly different (but comparable) input configurations of space weather conditions. This leads to the fact that even among different empirical models, there are minor differences in the magnitude of both the neutral density under moderate space weather conditions. It is widely known that during high solar weather conditions, there is variation of the neutral density in the thermosphere with height. Neutral density derived from two empirical models are compared for quiet time and storm time scenarios. Additionally neutral density and electron densities are compared from a physics-based model.

2. Empirical thermosphere models

- The calculation of the thermospheric density is conventionally carried out using empirical models such as the Naval Research Laboratory's Mass Spectrometer Incoherent Scatter Extension 2000 (NRLMSISE-00) model [Picone et.al, 2002] and The Jacchia-Bowman (JB2008) model [Bowman et.al, 2008]
- Model input in case of space weather phenomena are the F10.7 index as well as the Kp and Ap indices
- The models provide a nominal baseline that can be used to analyse the effects of geomagnetic storms on the thermosphere

3. Comparison of neutral density – empirical thermosphere models

- The JB2008 and the NRLMSISE-00 model have been developed over the years using data from different types of measurement campaigns such as accelerometers, orbit determination, and incoherent scatter radar

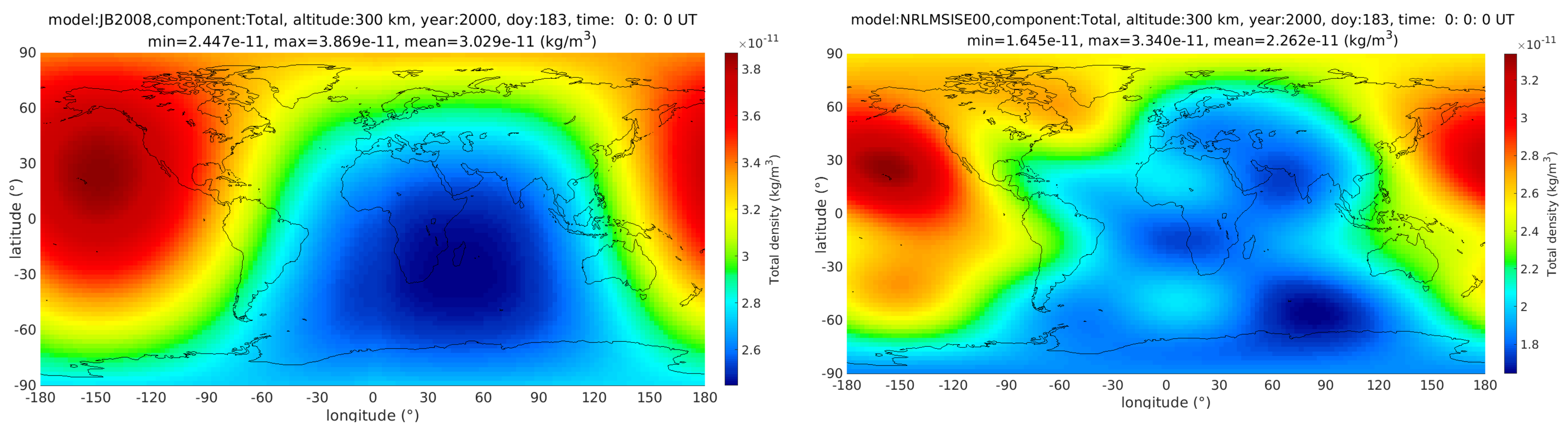

Figure 1: Comparison of two empirical thermosphere models during quiet solar activity period at July 1st, 2000 at 0 LT

- An exemplified comparison of the neutral density calculated from the two models at 0 LT and at a fixed altitude of 300 km on July 1st, 2000 (with a daily F10.7 value of 154.5 SFU) is shown in Fig. 1.
- The density variation of the JB2008 model has lesser structures compared to the NRLMSISE-00 model result. However, both models show variations over nearly the same range.
- Table 1 shows the variations in model predictions of the neutral density during high solar conditions compared with those at nominal conditions for two empirical and one physics-based model

Table 1: Statistics of the comparison of the two empirical models JB2008 and NRLMSIS-00 with the physics-based coupling model thermosphere-ionosphere model TIEGCM at 300 km altitude during a quiet period on 1 July, 2000 at 0 LT (left) and high solar activity period on 13 July 2000, shortly before the Bastille day event, at 0 LT (right)

Model	Maximum (Kg/m³)	Minimum (Kg/m³)	Mean (Kg/m³)
JB2008	3.86e-11	2.44e-11	3.02e-11
NRLMSISE-2000	3.34e-11	1.64e-11	2.26e-11
TIEGCM	4.47e-11	2.65e-11	3.56e-11

Model	Maximum (Kg/m³)	Minimum (Kg/m³)	Mean (Kg/m³)
JB2008	6.81e-11	5.01e-11	6.06e-11
NRLMSISE-2000	8.42e-11	3.90e-11	5.72e-11
TIEGCM	5.97e-11	2.92e-11	4.02e-11

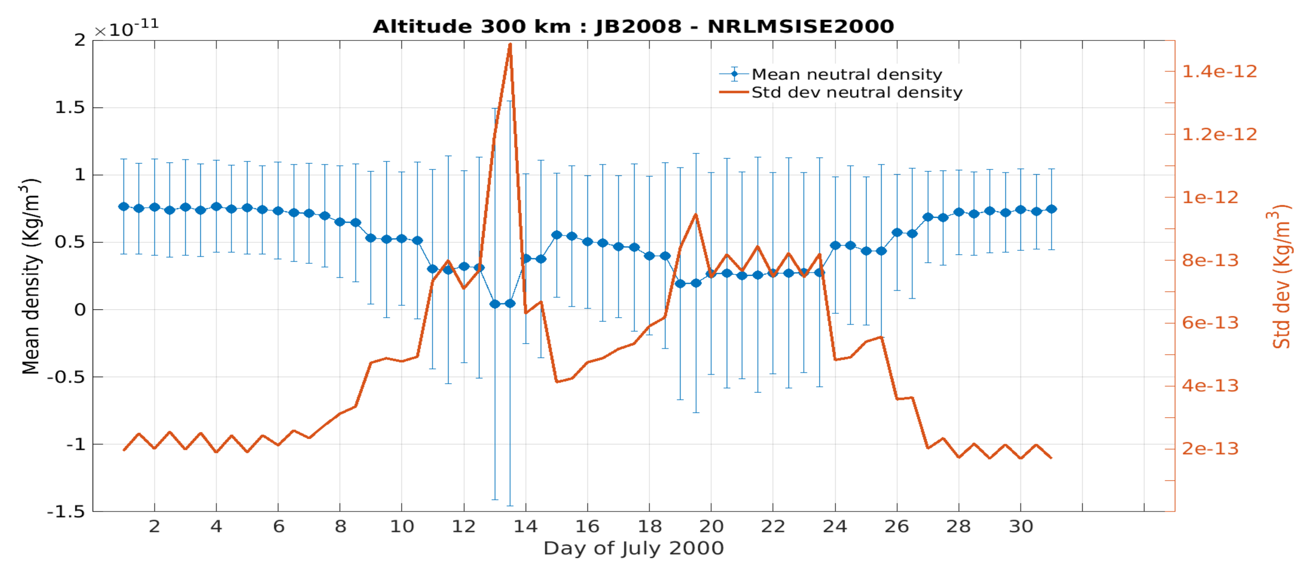

Figure 2: Empirical thermosphere model differences in mean neutral density at 300 km altitude during the entire month of July 2000 (with 12 hour sampling)

- Empirical models are based on geophysical and geomagnetic parameters within the processing algorithms
- Significant offset between the neutral density modeled from the two empirical models during high solar activity conditions as shown in Fig. 2

4. Comparison of neutral & electron density - physical thermosphere models

- The "Thermosphere Ionosphere Electrodynamics General Circulation Model" (TIEGCM) developed by NCAR provides a comprehensive, three-dimensional, non-linear representation of the coupled thermosphere and ionosphere system [Richmond et al. (1992)]
- The dynamic adaptation of the thermosphere to the solar EUV radiation at low latitudes and the auroral processes, associated with the solar wind, at high latitudes causes latitude-dependent variations in the electron density as shown in Fig. 3

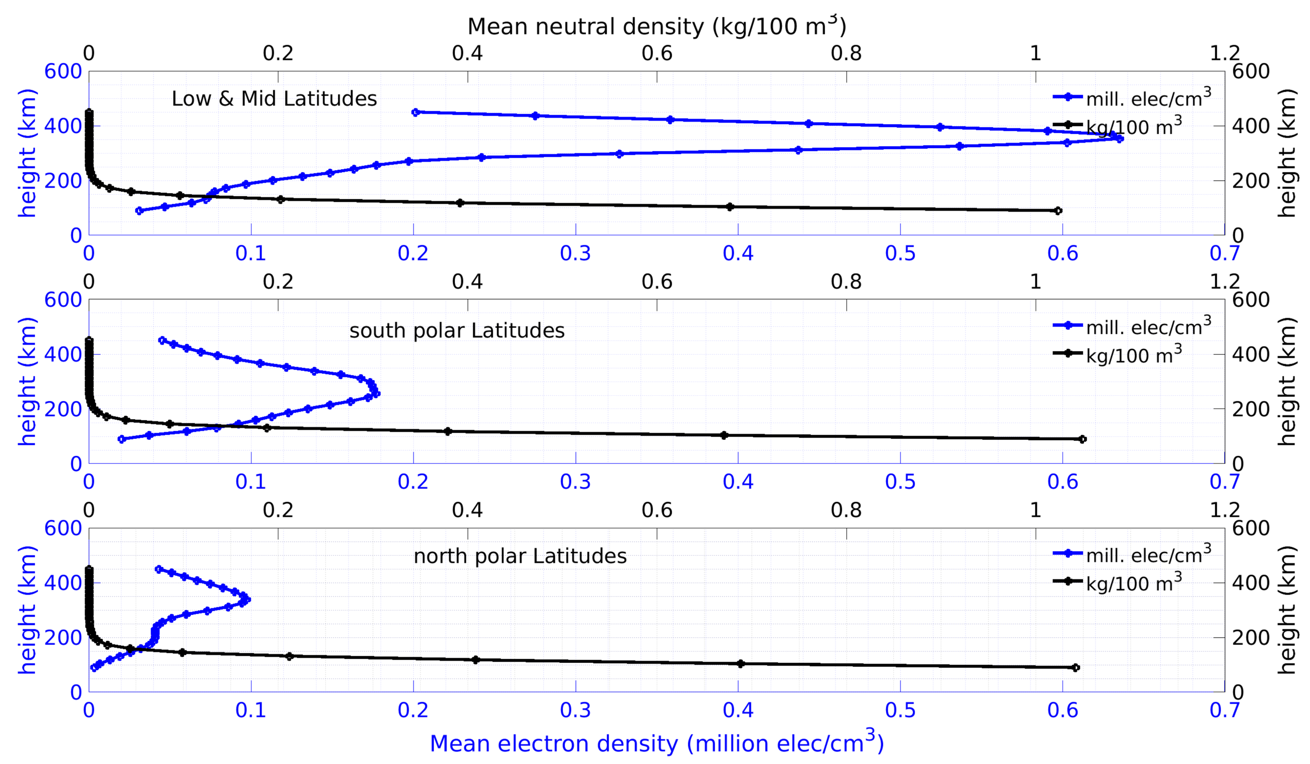

Figure 3: Latitudinal variations of the electron and the neutral density computed from TIEGCM under nominal conditions with F10.7 = 126 SFU

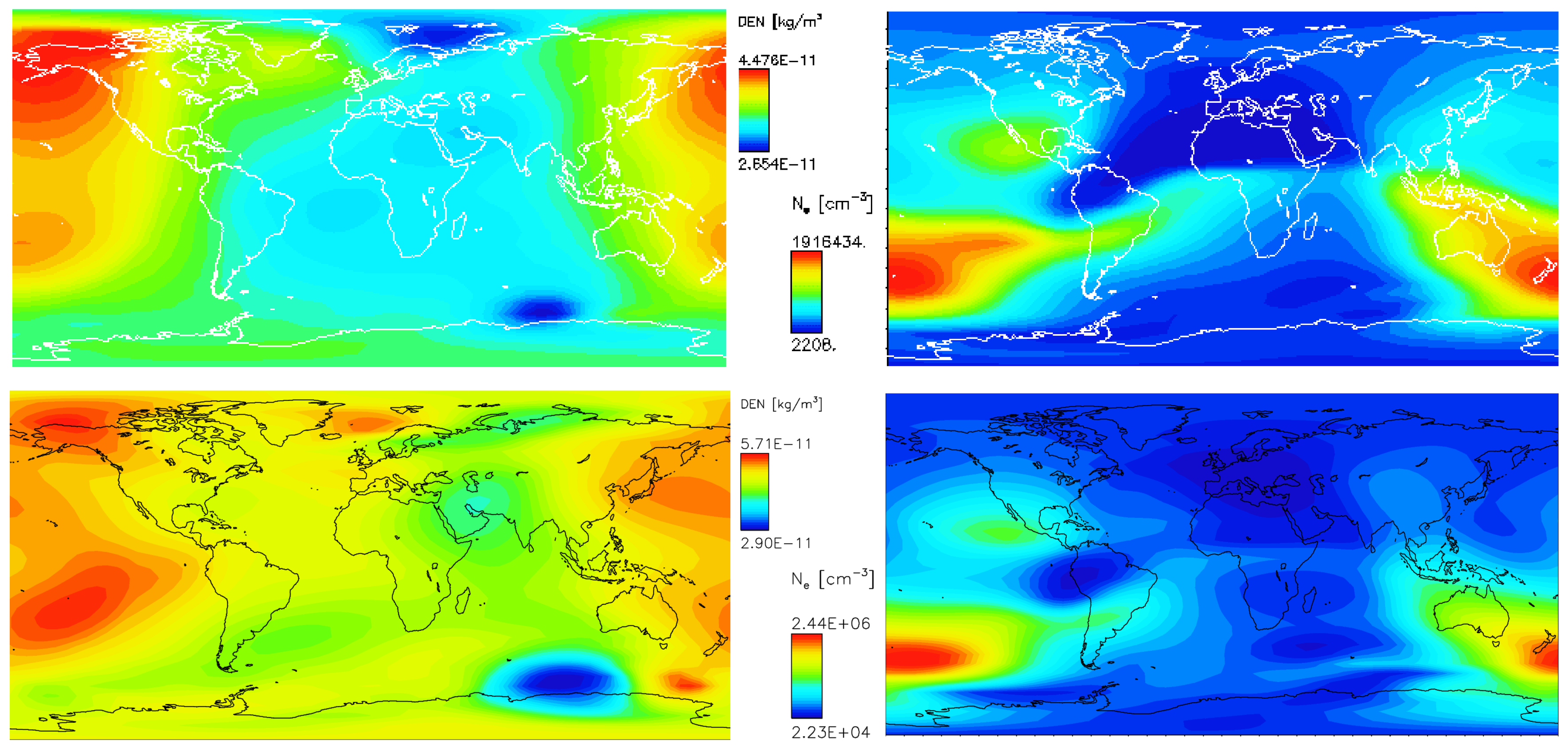

Figure 4: Neutral densities calculated from TIEGCM during quiet time on July 1st 2000 (top left) and at storm time on July 13th 2000 (bottom left). At the same times electron density values are calculated from TIEGCM.

- Figure 4 shows a comparison of the neutral and the electron density on two different days with distinct F10.7 values from TIEGCM. An increase of 22% in dayside electron density and 28% increase in dayside neutral density
- In comparison with an independent time period (January 2015), a change of 45% in the peak electron density can be seen between solar maximum conditions with a F10.7 index of 165 SFU and a ramp down phase of solar cycle with a F10.7 index of 126 SFU
- TIEGCM shows an additional variability due the physical processes in the thermosphere and not just those driven by the F10.7 index alone

5. Summary of main results

1. Differences in neutral density between the empirical models can be attributed to the systematic biases caused possibly by the different measurement techniques used to build the models and also the differences in parameterization of the storm time scenarios
2. Nearly constant mean and variance in quiet times for density differences. Larger variations observed in geomagnetic storm scenarios to which both the empirical models are sensitive
3. Variations of electron density with latitude, mainly caused by the differential EUV heating and polar auroral processes

Acknowledgement

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